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Antimatter Propulsion Systems

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Abstract— *Antimatter rockets are the rockets which use antimatter as their power source for propulsion purpose. Use of these rockets will make human beings capable of travelling farther distances like in light years, in working life time of a human being. It is a revolutionary development as far as rockets and space exploration is concerned. The objective of this paper is to study Antimatter and its use propulsion systems.*

1. INTRODUCTION

An Antimatter rocket uses antimatter as fuel instead of any hydrocarbon. Antimatter has the highest specific energy of any source known to man. An antimatter rocket is a class of rockets that uses antimatter as their power source. Antimatter propulsion systems have a far higher energy density and specific impulse than any other class of rocket. The performance of a rocket is given by specific impulse.

$I_{sp} = F/\dot{m}g$

Where F= Thrust produced

$\dot{m}$ =Mass flow rate of antimatter

g= acceleration due to gravity

According to research, in 1953 Eugene Sanger first proposed use of electron-positron annihilation to produce required thrust. Matter-antimatter explosion transfers complete mass of both objects into energy. It can be stated that the efficiency of this reaction is 100%. [1]Studies reveal that matter-antimatter annihilations yield the highest specific impulse and jet power of any propulsion system. It can yield specific impulses on the order of 10^7 seconds with thrust in the mega-Newton range proving it to be most efficient of all known propulsion systems.[3]

1.1 Antimatter

Antimatter is exact opposite of normal matter. As matter is made of particles like protons and electrons, similarly, antimatter is composed of antiparticles. These are mirror images of matter particles. They have the same mass as particles of ordinary matter but have opposite charge and quantum spin. Some antimatter discoveries are positrons(e+), Antiprotons(p-), anti-atoms(pairing of antiprotons and positrons).

2. CLASSIFICATION OF ANTIMATTER ROCKETS

2.1 According to application

2.1.1. Pure antimatter rockets

In this type of rockets the product of matter antimatter annihilation is released through a magnetic nozzle to produce thrust. This type of antimatter rocket is a beamed core configuration. The beam-core thruster uses a diverging magnetic field just upstream of the annihilation point between the antimatter matter. The magnetic field then directly focuses the charged particles as the exhausted propellant. The exhausted propellant travels close to the speed of light which causes the specific impulse of the system to be as high as 10 million seconds, but at very low thrust levels.

2.1.2. Thermal antimatter rockets

In this type Antimatter is used to heat a working fluid which is then used for propulsion. This type of system utilizes product of Antimatter annihilation to heat the propellant either directly or indirectly. This propellant is used to produce thrust. Here, gamma rays are used to heat a solid engine core. Gamma rays are the product of positron-electron annihilation. Hydrogen gas is ducted through this core, which is heated and expelled from a rocket nozzle. This is solid core engine. In some cases, positron annihilation is made to occur within a compressed xenon gas to produce a cloud of hot gas. This causes the surrounding layer of gaseous hydrogen to heat up and expand to produce thrust. Also the gamma rays may be used to heat an ablative sail, with the ablated material to provide thrust.

2.1.3. Antimatter power generation

These are the rockets that heat a working fluid to generate electricity for some form of electric spacecraft propulsion system. Antimatter annihilations are used to directly or indirectly to heat a working fluid, as in nuclear thermal rocket, but the fluid is used to generate electricity, which is then used to power some form of electric space propulsion system.

2.2. According to energy transfer

2.2.1. Solid core

In this type the energy is transferred to a propellant in tungsten metal matrix heated by annihilating gamma rays. Propellant is inducted into the hot core from the propellant tank and expanded through a nozzle to generate thrust. It also consists of a coolant pipe to prevent the overheating of outer body of engine. Its performance is limited (lsp - 10^3 sec) due to melting temperature of tungsten. Its efficiency is more than 80%. The antimatter energy conversion and heating efficiencies are typically high due to the short mean path between collisions with core atom. A Solid core Engine is shown in Fig. 1.

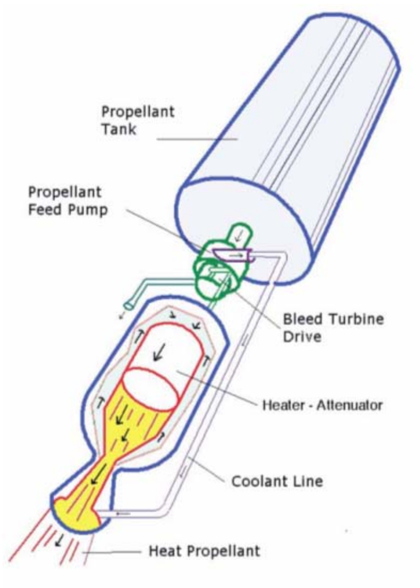

Fig. 1: Solid Core Engine

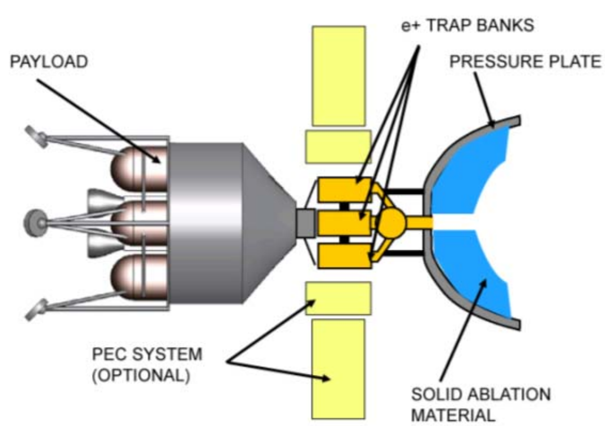

Fig. 2: Solid Ablation

2.2.3. Gas core

Fig. 3 shows a Gas core system. In this engine, the energy is transferred to gas propellant which is directly heated by annihilation of gamma rays. It is an improvement over solid core. It consists of a storage unit in which gamma rays from matter antimatter annihilation are stored. The gamma rays are bombarded on a hot gas core which in turn releases radiations to produce thrust. It can be used at high operating temperatures. But the flowing multi-fluid is unstable at boundaries which may ionise and create plasma. The longer mean free path for thermalization and absorption results in much lower energy conversion efficiencies ($< 35\%$).

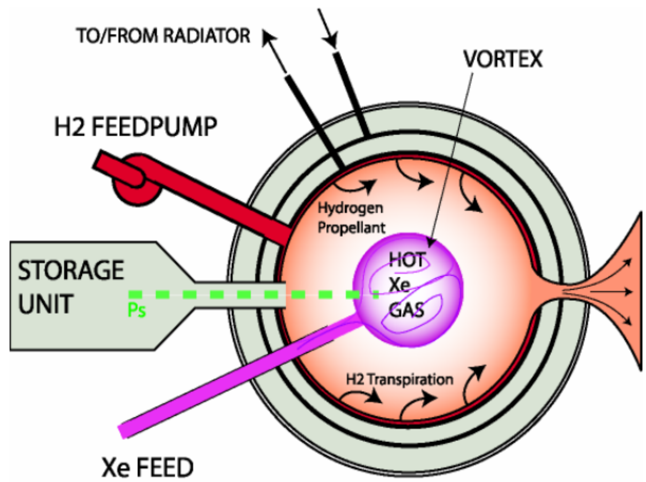

Fig. 3 Gas Core

2.2.2. Solid Ablation

Energy is transferred to a material that ablates off surface of a pusher plate. It is very simple in design. Here, half of the gamma rays do not strike the pusher plate due to which its maximum efficiency is 50%.This concept is used in the 21st century Sanger Rocket.

2.2.4. Plasma core

In plasma-core the gas is allowed to ionize and can be operated at higher effective temperatures. Heat loss is effectively reduced by magnetic confinement in the reaction chamber and nozzle. The performance is extremely high (*Isp* - 10^4 - 10^5 sec). It consists of a ring shaped magnet which is used to generate the magnetic field for the nozzle. A radiation shield is placed between the magnetic nozzle and the engine to protect the engine from the gamma rays produced by the antiproton proton annihilation and the decay of neutral pions. A shadow shield is placed between the magnetic nozzle and the rest of the vehicle to protect the vehicle from exposure to radiation. Antiprotons are injected into the plasma core, annihilating and heating the plasma. Heat is rapidly transferred to the propellant, which is expelled from the drive at high velocity. The excess plasma is then diverted to an ion thruster to provide additional thrust.

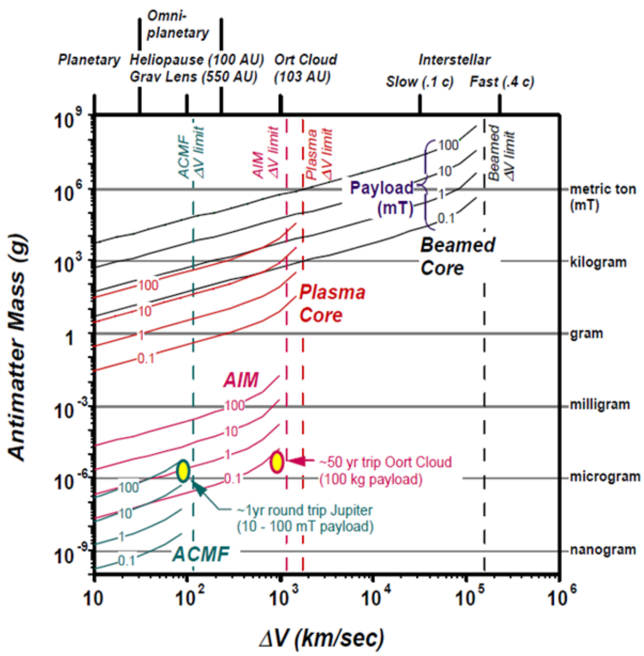

Fig. 5

Fig. 5 shows the mass of antimatter required for different types of systems for various distances. It can be clearly seen from the Fig. that the mass of Antimatter required is very less but the thrust produced, velocity of travel and the distance covered in considerably large. These can be surely used for unmanned missions to send probes on the nearer planets. As far as Interstellar missions are considered Beamed core configuration is the most ideal for use. It requires 1 kilogram of Antimatter to travel with a velocity of 10^5 km/sec.

3. ADVANTAGES AND DIFFICULTIES

Of all the types explained earlier a Thermal antimatter propulsion and Power generating antimatter propulsion systems could be used in nearest future as it makes use of Antimatter as well as some conventional fuels for propulsion. However, these systems have its own advantages and disadvantages.

3.1. Advantages

1. Antimatter is hundred percent efficient as its whole mass is converted into Energy after annihilation with matter.

2. For propulsion of spacecraft the amount of Antimatter required will be very less. A ten-gram of Antimatter would be enough to send manned spacecraft to Mars. This mass is negligible as compared to Hydrogen or any conventional fuel used.

3. Specific impulse of Antimatter is very high. The specific impulse could be greater than 10,000,000secs.

4. Speed of Antimatter particles is about 94% that of speed of light which provides extremely high thrust. This helps to cover the larger distances in less time.

3.2. Difficulties

The production and storage of Antimatter are the major difficulties with systems using Antimatter.

3.2.1. Production

Problem with Antimatter is that it does not exists naturally. Production of Antimatter in required amount is a difficult task. A few gram of Antimatter will take many years. Large-scale production techniques are not yet developed. Creation of Antimatter requires extremely large energy input at least equivalent to the rest energy of the created particle/antiparticle pairs. At CERN, Anti protons and positrons are being produced and stored to study its properties using a Large Hadron Collider LHC. Fig. 6. shows the increase in mass of antimatter produced per year.

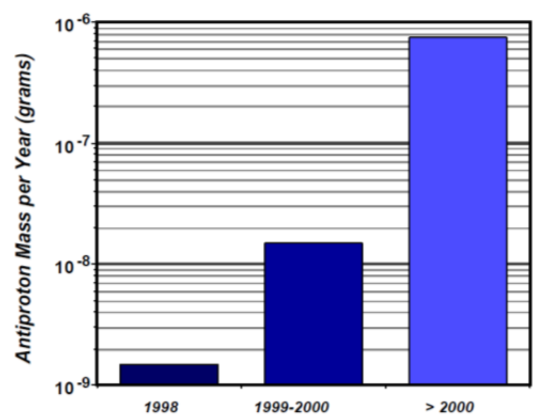

Fig. 6: Increase in Antiproton mass per year

3.2.2. Storage

Antimatter cannot be stored in a container made of ordinary matter because it reacts with any matter, it touches, annihilating itself and releasing total amount of the energy contained in both the particles. Storage of Antimatter is typically done by trapping electrically charged frozen anti-hydrogen pellets in Penning or Paul traps. At CERN they are successful in trapping antiprotons for 1000 seconds and are still giving their best to increase the storage time.

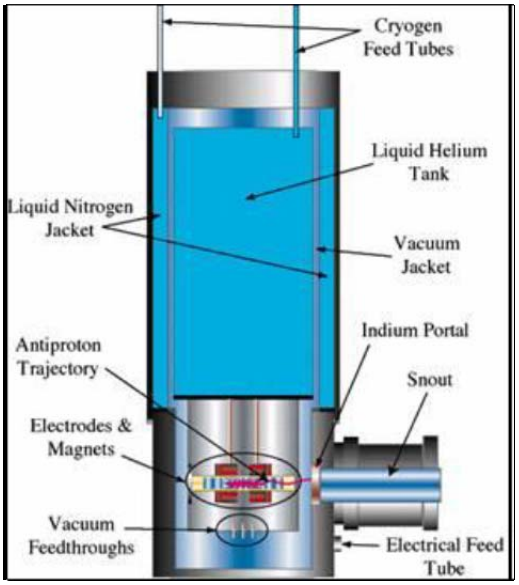

Fig. 7: Penning trap

Fig. 7. shows a Penning trap. A Penning Trap is an evacuated electromagnetic bottle in which charged particles of antimatter can be suspended. Anti-electrons, or positrons, are difficult to store in this way, so antiprotons are stored instead. It is capable of storing 10^{10} antiprotons for one week using electric and magnetic fields. The heart of a Penning trap where a cloud of antiprotons is stored is kept cold and quiet by using liquid nitrogen and helium. It has a stable magnetic field. For complete antimatter propulsion it is thought that 10^{20} anti-protons will need to be stored. Storage is possible because it may be controlled in magnetic fields.

3.2.3. Cost

Antimatter is the most expensive substance on Earth about $62.5 trillion per gram. Production and storage involves a huge cost.

3.2.4. Extraction of energy

A secondary problem is the extraction of useful energy or momentum from the products of antimatter annihilation, which are primarily in the form of extremely energetic ionizing radiation. The antimatter mechanisms proposed to date have for the most part provided plausible mechanisms for harnessing energy from these annihilation products.

When Antimatter is compared with the conventional fuel used in the propulsion systems then it is observed that the exhaust released from the antimatter propulsion systems is highly radioactive and lethal to the biodiversity.

According to CERN, the pace with which technology is developing and studies being carried out, it is possible that this technology will be implemented in deep space exploration in next decade or so. It assures that the day is not far when humans will be discovering deep interstellar bodies, probably another solar system. However, scientists are doubtful about the use of Antimatter Rockets for manned missions on farther planets, but they are quite sure that it can be used to send unmanned probes in deep space. The implementation of this technology will require the elimination of the difficulties explained earlier. Efforts are being made to reduce the required mass of antimatter for propulsion in order to reduce the overall cost of production and storage.

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